Evidence for opposite polarities in the light bridge of sunspot: possibility for low altitude reconnection

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Abstract. A multi-wavelength photometric analysis of the sub-structure of a sunspot light-bridge in photosphere and chromosphere is performed in NOAA Active Region 8350 taken on 1998 October 8. The data set consist of a 100 min time series of 6302.5 nm, and five positions in blue and red wings plus line center of H-alpha. The observations were obtained from the Dunn Solar Telescope (DST) at NSO/SP. We found the following results: (1) Horizontal flows with speed 4 - 6 km/s observed in the chromosphere. (2) Brightening is seen in H-alpha line center at the light-bridge location with bidirectional inflow which may indicate a high level of magnetic stress. (3)Ejection in H-alpha was found after brightening, (4) Magnetograms of the same region reveal opposite polarity in light-bridge with respect to the umbra. These facts support that low-altitude magnetic reconnections can result in the magnetic cancellation region that observed on the photosphere.

Key words: Sun: magnetic fields- Sun: photosphere – sunspots Sun: chromosphere

1. Introduction

Large sunspots often have a complex structure on spatial and temporal scales. The pattern at the visible surface reflects in some way the structure of the deeply rooted magnetic field and the magneto-hydrodynamic and thermodynamic processes ongoing in the deeper layers inaccessible to direct observations. The presence of umbral bright features (umbral dots and light-bridges) can be explained theoretically either in terms of cluster model, where the umbra is formed by tight bundle of isolated thin flux tubes, separated by field-free columns of hot plasma (Parker 1979a,b; Choudhuri 1986), or in the terms of magneto convection taking place in a coherent but homogeneous large flux tube. Numerical simulations of magneto convection (Weiss et al. 1996; Blanchflower et al 1998) show that when increasing the intrinsic magnetic field strength up to the conditions present in a sunspot umbra, the flow structure becomes completely controlled by the magnetic field. Thus the convective cells are prevented from expending. This leads to a pattern of small and roundest convective cells regularly ordered in a grid or chain like structure (umbral dots). For lower field strengths the magnetic field is dominated by the convective flows, so that the flow field becomes chaotic and the growing convective cells push out the magnetic field such as in the case of light-bridges. According to Vazque (1973), the formation of so-called "photospheric light-bridges" in sunspot or pores is a result of the decay of the spot and restoration of the granular surface. A positive correlation between the brightness and up flow velocities was reported by Rimmele (1997), who considered it as evidence for the magneto convective origin of photospheric light-bridges. Light bridge have been considered to have the same magnetic polarity as that of the sunspot umbra, while a systematic reduction of the magnetic field strength in light bridges compared with the surrounding umbra and the field is more inclined from vertical was found by Beckers & Schroter(1969), Abdusamatov (1970), Kneer (1973), and more recently by Wieher & Degenhardt (1993), Ruedi et al. (1995), and Leka (1997).

2. Observations and data reduction

The observations for the current investigations were made at National Solar Observatory, Sac Peak on 1998 October 08 using 76-m DST from 14:05 to 15:45 UT. The main instrument used for these observations was the Universal Birefringent Filter (UBF). The surge activities along the light-bridge in NOAA AR 8350 (N19^{o}, W10^{o}) were observed using UBF. The UBF is a tunable Lyot filter with a passband that can be varied between 180 and 250 mA as a function of wavelength. The UBF was tuned into the red and blue wings of Fe I 557.6, Fe I 630.2 and Hα 656.3 nm. The Fe I 557.6 nm line, which forms at an altitude of about 320km (Bruis, Lites, & Murphy 1991), is used to obtain Dopplergrams at different heights in the solar atmosphere. The Fe I 557.6 nm line has the advantage of being a "nonmagnetic" line; i.e., the effective Lande factor is g=0, providing a clean Doppler signal without any cross talk from the magnetic field. In addition to above dopplergrams a sequence of filtergrams were also taken in continuum at 557.19 nm and line center of 557.6, 630.25 and 656.3 nm. The Fe I 630.25 was used to obtain line-of-sight (LOS) magnetograms. A quarter-wave plate mounted in front of the UBF enabled us to record left and right hand circular polarization (LCP and RCP) filtergrams respectively. The magnetograms were generated from these filtergrams that taken in the blue wing of the Fe I 630.25 nm with an offset of 0.008 nm from line center.

After flat and dark current correction the UBF filtergrams were corrected for residual differential motions visible across the extended FOV seeing effects by using a destretch algorithm. We computed Dopplergrams and magnetograms in the usual manner (see Rimmele, 2004 for more details). The calibration factor for the magnetograms was derived in a fashion similar to what described by Berger & Title (2001), Rimmele (2004). However our magnetograms were calibrated for weak field approximation. The noise floor in the magnetograms was determined from the FWHM of a Gaussian fit to the histogram of the calibrated magnetogram (see Fig 5 of Berger & Title 2001). The noise level for our magnetograms is approximately 60 G without averaging.

3. Results

H-alpha observations:

As shown in Figure 1 the light-bridge has two arms angled at 150^{o}. The average width of the left and right arms is 1.53 and 1.1 Mm respectively, while they extend in length 2.14 and 2.89 Mm respectively**.** Dark lane was also visible along the length of the left and right arms of the light-bridge.

Movie of H-alpha line center filtergrams showed bidirectional plasma flow. At the edges near sunspot penumbra plasma flow was seen in both the arms of light–bridge with speed 4-6 km/s towards penumbra, which, however, began from vertex of two arms. However near vertex in upper left arm flow was in opposite direction so as to merge into dark umbra and finally it became umbral dots. The brightening along lower left arm was seen throughout the observing interval. The relative peak intensity of these bright patches to the quiet chromospehere was 1.67. A filament observed on neutral line above the light-bridge moved upward and during this time dark surges from lower left arm were seen. Following to dark surge activity bright surge ejection was observed moving towards right direction with velocity 4.5 Km/s., as shown in Figure 1 (a-j).

Magnetic configuration:

The continuous mass ejection from light-bridge was considered to be an evidence of emerging flux (e.g. Kurokawa & Kawai 1993). Our high resolution magnetograms (Figure 2) showed, for the first time, a remarkable feature of opposite polarity in light-bridge with regarding to umbra, which had not been reported so far. As shown in Figure 2, white arrow indicates negative polarity while black shows positive polarity. Evidence of enhanced magnetic field cancellation became evident at the foot points of the ejection site where brightening was observed in H-alpha line. Since sunspot is located near disk center hence minimizing the possibility of projection effect. We compared our sunspot with Kitt-Peak magnetogram and found that the same sunspot light bridge showing less magnetic field strength which oppose our findings. We have done one test, we scaled down resolution of sunspot that of the Kitt-Peak magnetogram resolution and found that our scaled magnetogram showing reduced field strength as Kitt-peak magnetogram. Hence the reduced field strength is most possibly due to low resolution and hence averaging of opposite polarizing signal. So there is no doubt to state that opposite polarity is not artifact. However we can't make quantitative measurement of flux since our magnetograms suffers from saturation at higher field strength.

4. Discuaaion and conclusions

It has been widely known that the bright knots and the plasma ejection observed in the chromosphere are driven by an emerging flux that reconnects successively with the ambient open fields. Wang & Shi (1993) and Yoshimura et. al. (2003) argued that magnetic flux cancellation may lead to magnetic reconnection because the cancellation always takes place in the interface region between different magnetic field systems. The frequent mass ejection observed in the chromosphere could be the signature of such reconnection in lower atmosphere triggered by magnetic flux cancellation that taking place between light-bridge and umbra. Recent studies have shown that the low altitude reconnections are the direct causes of the ubiquitous micro flares in the emerging flux regions (Mandrini et al. 2002; Schmineder et al. 2002, Liu and Kurokawa 2004). The low altitude reconnection process effectively helps to inject dense plasma into the upper atmosphere. It is evident from our magnetograms that polarity of light bridge and umbra are opposite and therefore continuous magnetic field cancellation may be a dominant process to trigger the mass ejection seen in our chromospheric filtergrams. Our finding gives support to the possibility of low altitude reconnection. Strong upflow in central part of light bridge and downflow at edge of light bridge (Bharti 2006) plays important role for flux transport from below the surface.

To understand plasma ejection from light bridge, high resolution spectro polametric observation are needed. Hopefully with DLSP phase-II it could be possible in near future.

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Figure captions:

Figure 1. Snapshots of H-alpha line center filtergrams. Brightening along light bridge and darkening above light bridge shows micro flares and surges respectively.

Figure 2. Magnetograms, arrow shows another flux cancellation site.

References

G. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," *Phil. Trans. Roy. Soc.* London, vol. A247, pp. 529-551, Apr. 1955.

J. Clerk Maxwell, *A Treatise on Electricity and Magnetism,* 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp. 68-73.

I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in *Magnetism,* vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271-350.

Abdusamatov K.I., "The Structure of the Magnetic Field in a Sunspot with a Photospheric Light-Bridge at Two Levels in the Solar Atmosphere", 1970, Soviet Astron. AJ 14/1, pp. 64

Beckers, J. M., and Schroter, E.H., "The Intensity, Velocity and Magnetic Structure of a Sunspot Region. IV: Properties of a Unipolar Sunspot", 1969,Sol. Phys., 10, pp. 384

Berger, T.E., & Title, A. M., "On the Relation of G-Band Bright Points to the Photospheric Magnetic Field", 2001, ApJ, 553, pp. 449

Bharti, L., Ph.D. thesis, 2006 (in prepration)

Blanchflower, S.M., Rucklidge, A. M., and Weiss, N. O. "Modelling photospheric magnetoconvection",1998, MNRAS, 301, pp. 593

Choudhuri, A. R., "The dynamics of magnetically trapped fluids. I – Implications for umbral dots and penumbral grains" 1986, ApJ, 302, pp. 809

Kneer, F., "On Some Characteristics of Umbral Fine Structure", 1973, Sol. Phys., 28, pp. 361

Leka, K. D., "The Vector Magnetic Fields and Thermodynamics of Sunspot Light Bridges: The Case for Field-free Disruptions in Sunspots", 1997, ApJ, 484, pp. 900

Liu, Y. and Kurokawa, H., "On a Surge: Properties of an Emerging Flux Region", 2004, ApJ, 610, pp. 1136

Mandrini, C. H., Demoulin, P., Schmieder, B., Deng, Y. Y., & Rudawy, P., "The role of magnetic bald patches in surges and arch filament systems", 2002, A&A, 391, pp. 317

Parker, E. N., "Hydraulic concentration of magnetic fields in the solar photosphere. VI - Adiabatic cooling and concentration in downdrafts", 1978, ApJ, 221, pp. 368

Parker, E. N., "Sunspots and the physics of magnetic flux tubes. IX - Umbral dots and longitudinal overstability", 1979, ApJ, 234, pp. 333

Rimmele, T. R., "Evidence for Magnetoconvection in a Sunspot Light Bridge", 1997, ApJ, 490, pp. 458

Rimmele, T. R., "Plasma Flows Observed in Magnetic Flux Concentrations and Sunspot Fine Structure Using Adaptive Optics", 2004, ApJ, 604, pp. 906

Ruedi, I., Solanki, S. K., and Livingston, W. C., "Infrared lines as probes of solar magnetic features. X. HeI 10830A as a diagnostic of chromospheric magnetic fields", 1995, A&A, 293, pp. 252

Schmieder, B., Pariat, E., Aulanier, G., Georgoulis, M. K., Rust, D. M., and Bemasconi, P. N., "Flare Genesis Experiment: magnetic topology of Ellerman bombs", 2002, in 10th European Solar Physics Meeting, ed. A. Wilson (ESP-SP- 506; Noordwijk: ESA), pp. 911

Vazquez, M., "A Morphological Study of the Light-Bridges in Sunspots", 1973, Sol. Phys., 31,pp. 377

Weiss, N. O., Brownjohn, D. P., Matthews, P.C., and Proctor, M. R. E., "Photospheric Convection in Strong Magnetic Fields", 1996, MNRAS, 283, pp. 1153

Wiehr, E., and Degenhardt, D., "Magnetic field strengths in umbral dots", 1993, A&A, 278, pp. 584

Wang, J., and Shi, Z., "The flare-associated magnetic changes in an active region. II - Flux emergence and cancellation", 1993, Sol. Phys., 143, pp. 119

Yoshimura, K., Kurokawa, H., Shimojo, M., and Shine, R., "Close Correlation among Halpha Surges, Magnetic Flux Cancellations, and UV Brightenings Found at the Edge of an Emerging Flux Region", 2003 , PASJ, 55, pp. 313